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OPACITY STANDARDS

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ABSTRACT

Opacity of paper is commonly specified by the contrast-ratio method. According to this method the reflectance of the material backed by a perfectly absorbing surface divided by its reflectance when backed by a highly reflecting material such as magnesium oxide is taken as an index of opacity. Magnesium oxide, itself, is, however, commonly not used as the white backing because of its fragility; nor is the white backing placed in actual contact with the sample. Because of these and other sources of error, opacimeters frequently give erroneous results. Standards of opacity made of permanent material serve to check and to calibrate such instruments. Such standards made of opal glass are described, the theory of their application is given, and results of tests by their use reported. It is found that TAPPI opacity corresponds to a reflectance of white backing in contact with the sample of about 0.89.

CONTENTS

I. INTRODUCTION

The opacity of a sheet of any material (paper, cloth, porcelain, and the like) may be specified by its contrast ratio. Contrast ratio is defined [1] as the apparent reflectance of the material backed by a perfectly absorbing surface divided by its apparent reflectance when backed by magnesium oxide. Because of the fragility of magnesium oxide surfaces, opacimeters for routine determinations are commonly made with white backings other than MgO and sometimes these surfaces are protected by the interposition of an air space, a cover glass, or both. The official method of the Technical Association of

[1] Circular of the Bureau of Standards C63, *Specification of the transparency of paper and tracing cloth*, May 17, 1917.

the Pulp and Paper Industry (the TAPPI method)[2] for the determination of opacity of paper is an example of this practice. The errors which may arise through these deviations from the definition have been discussed for perfectly diffusing, nonabsorbing materials and the theoretical expressions derived were shown to apply closely to a few paper and opal-glass samples.[3]

A standard of opacity made of a permanent material is of use in checking the adjustment of opacimeters. Two sorts of such standards have been prepared. They are (1) solid-opal glass, ground to nearly uniform thickness, one face fire-polished, the other fine-ground, and (2) flashed-opal glass, the flashed face fire-polished, the other face fine-ground. It is the purpose of this paper to describe tests of these standards, to outline the method of checking an opacimeter by their use, and to show the relation of TAPPI opacity to contrast ratio.

II. THEORETICAL RELATIONS

In the interpretation of tests on the standards use is made of three relations derived theoretically from the assumptions (1) that the samples are homogeneous, (2) that both sample and backings reflect light in a perfectly diffuse way, and (3) that the samples are sufficiently thin that no appreciable amount of light is lost through the edges. The following symbols are used:

$R_0 \equiv$ the reflectance of the sample when in contact with a backing of zero reflectance,

$R_1 \equiv$ the reflectance of the sample when in contact with a backing of unit reflectance,

$R_{R'} \equiv$ the reflectance of the sample when in contact with a backing of reflectance, R',

$C \equiv R_0/R_1$, called the ideal contrast ratio,

$C_{.97} \equiv R_0/R_{.97}$, called the true contrast ratio according to the definition which specifies as the white backing magnesium oxide, for which $R' = 0.97$,[4]

$C_{R'} \equiv R_0/R_{R'}$, called the measured contrast ratio when the reflectance of the surface or cavity in contact with the back of the sample is R',

$s \equiv$ the number of standard scattering layers required to duplicate the scattering produced by unit thickness of the sample,

$x \equiv$ the thickness of the sample varying from zero up to the thickness for which light escaping through the edges of the sample becomes appreciable,

$R_\infty \equiv$ the reflectivity of the material, that is, the reflectance of the material of the sample in a layer infinitely thick.

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[2] No. T425m, obtainable from the association at 122 East 42d Street, New York, N.Y.

[3] D. B. Judd, *Sources of error in measuring opacity of paper by the contrast-ratio method.* BSJ.Research 12, 345 (1934);RP660.

[4] International Critical Tables, 5, 262.

1. MEASURED CONTRAST RATIO AS A FUNCTION OF REFLECTANCE OF WHITE BACKING AND REFLECTANCE OF SAMPLE

$$C_{R'}=\frac{C(1-R'R_0)}{C(1-R')+R'(1-R_0)} \tag{1}$$

This formula may be derived by argument analogous to that used in deriving equation 4 in a previous paper [5] which applies to nonabsorbing samples. For a nonabsorbing sample, $C=R_0$; for this case equation 1 reduces to the previous result. Similar lines of reasoning have been used by Channon, Renwick, and Storr [6] and, still earlier, by Stokes [7] in the derivation of an expression for $R_{R'}$. The expression for $C_{R'}$ for nonabsorbing samples also follows directly from a formula for $R_{R'}$ derived by Kubelka and Munk by independent argument.[8]

2. MEASURED CONTRAST RATIO AS A FUNCTION OF THICKNESS AND SCATTERING POWER OF THIN SAMPLES

$$\left.\begin{aligned} C_{R'} &\equiv R_0/R_{R'} \\ R_{R'} &= \frac{(R'-R_\infty)/R_\infty - R_\infty(R'-1/R_\infty)e^{sx(1/R_\infty-R_\infty)}}{(R'-R_\infty)-(R'-1/R_\infty)e^{sx(1/R_\infty-R_\infty)}} \end{aligned}\right\} \tag{2}$$

The expression for $R_{R'}$ is the one derived by Kubelka and Munk [9] as their equation 5. R_0 is found by setting $R'=0$.

3. MEASURED CONTRAST RATIO AS A FUNCTION OF REFLECTANCE OF THE BLACK BACKING FOR THIN, NONABSORBING SAMPLES

$$R_{R'}/R_1=\frac{C+R'-2R'C}{1-R'C}$$

This formula is derived by argument similar to that used for equation 4 in a previous paper [10]. Since the black-lined cavities used in opacimeters commonly reflect less than 0.002, application of this formula discloses that errors from deviation of the reflectance of the black backing from zero are negligible; for paper samples they are less than 0.001. No further attention will be paid to this source of error.

III. TESTS OF THE STANDARDS

Five solid-opal-glass standards (A1 to A5)[11] and 5 of the flashed-opal standards (B1 to B5) were prepared in the form of rectangles 5 by 20 cm; the thicknesses are about 1.5 mm. The standards were engraved with the identifying marks.

[5] See footnote 3, p 282.

[6] H. J. Channon, F. F. Renwick, and B. V. Storr, *The behavior of scattering media in fully diffused light*, Proc. Roy. Soc., London, [*A*] **94**, 222 (1918). See their equation 2.

[7] G. G. Stokes, *On the intensity of the light reflected from or transmitted through a pile of plates*, Proc. Roy. Soc., London, **11**, 545 (1860–62). See his equation 6.

[8] P. Kubelka and F. Munk, *Ein beitrag zur optik der farbanstriche*, Z. f. Techn. Phys. **12**, 593 (1931). See their equation 8.

[9] See footnote 8.

[10] See footnote 3, p. 282.

[11] The use of solid-opal glass with fine-ground surfaces for standards of opacity was suggested to the Bureau by J. W. Forrest, of Bausch and Lomb Optical Co. in the summer of 1933.

1. UNIFORMITY

Since the five solid-opal-glass standards were cut from the same sheet it may be expected that thickness is the chief determinant of opacity. This does not apply, of course, to the standards of flashed-opal glass. Accordingly, an attempt was made to correlate opacity with thickness for the solid-opal-glass standards. Two measurements of contrast ratio were made on each of the 10 standards, one measurement applying chiefly to the engraved end, the other chiefly to the end not engraved. Table 1 shows the results of this test.

TABLE 1.—*Uniformity of the standards*

Standard	Engraved end		End not engraved		Standard	Engraved end		End not engraved	
	Thickness	$C_{.97}$	Thickness	$C_{.97}$		Thickness	$C_{.97}$	Thickness	$C_{.97}$
	mm		*mm*			*mm*		*mm*	
A1	1.52	0.839	1.45	0.837	B1	--------	0.477	--------	0.490
A2	1.53	.834	1.44	.834	B2	--------	.474	--------	.467
A3	1.54	.834	1.45	.829	B3	--------	.476	--------	.471
A4	1.62	.842	1.51	.836	B4	--------	.474	--------	.478
A5	1.70	.846	1.60	.846	B5	--------	.498	--------	.508

These values of contrast ratio represent means of 10 settings each; the uncertainty is about 0.004. It may be seen that the variations in opacity from one end of the standards to another indicated by these measurements are scarcely, if at all, significant for the solid-opal-glass standards. The correlation with thickness is suggested but is somewhat masked by experimental error. The variation in opacity from one end to the other of two (B1 and B5) of the flashed-opal standards is significant. It is concluded that the thickness of the diffusing layer of these flashed-opal-glass standards is importantly inconstant and that on the contrary the thickness of the solid-opal-glass standards is not importantly inconstant.

2. CLEANABLENESS OF THE FINE-GROUND SURFACES

As stated before, one face of each standard was left fire-polished; this face is always toward the white backing and is not viewed by the photometer. The other face of each standard is fine-ground. Since there may be a difference between the surface obtained by fine-grinding clear glass and that obtained by fine-grinding opal glass, because of nonhomogeneity of the latter, the two surfaces were tested separately to determine the degree to which they may be cleaned.

The method of test was: (1) Wash thoroughly with soap and water by rubbing with the finger tips, and measure contrast ratio; (2) rub with lampblack and machine oil, wash with soap and water, and measure contrast ratio; (3) repeat process (1); (4) rub with lampblack and machine oil, wash with gasoline, wash with soap and water, and measure contrast ratio.

It was found that the fine-ground surface of clear glass was cleaned by washing with soap and water as far as visual inspection could distinguish; measurement of contrast ratio, however, revealed that an appreciable amount of lampblack remained. This residual amount was removed by washing both with gasoline and with soap and water.

Visual inspection of the fine-ground surface of opal glass showed that all the washings had failed to remove the lampblack completely, but measurement showed that the washings had succeeded in restoring the original value of contrast ratio. Since soiling with oil and lampblack is regarded as a rather severe test, no further attempt was made to find a more effective cleaning method.

3. APPLICABILITY OF THE FORMULA FOR THIN SAMPLES TO THE STANDARDS

The appreciable thickness (1.5 mm) of the standards might be sufficient to make formulas inapplicable which were derived on the assumption of no loss of light through the edges. Accordingly, measured contrast ratio, $C_{R'}$, was found for standards A2 and A3 using three different white backings, fresh magnesium carbonate ($R'=0.96$), old magnesium carbonate ($R'=0.92$) and cardboard ($R'=0.78$). These values of reflectance were found for nearly diffuse illumination and perpendicular viewing relative to magnesium oxide whose reflectance is taken as 0.97.[12] The reflectance of the solid-opal-glass standards backed by black velvet, R_0, was found in the same way to be 0.71. Measured contrast ratio was determined on the original model designed and used by Priest.[13] The color temperature of the illuminant for measurement of both reflectance and contrast ratio was about 2,400 K. Care was taken to insure that the white backings were within 0.2 mm of the standards over the entire effective area (4 cm diam.). Table 2 gives the values of $C_{R'}$ found in this way and values of $C_{.97}$ found from them by application of formula 1. This application consisted of two stages: First, ideal contrast ratio, C, was found from formula 1 in terms of the known quantities, $C_{R'}$, R_0, and R'; then true contrast ratio, $C_{.97}$, was found for these values of C by substituting $R'=0.97$ directly in the formula.

TABLE 2.—*Measured contrast ratio and true contrast ratio*

	Standard A2		Standard A3	
R'	$C_{R'}$	$C_{.97}$	$C_{R'}$	$C_{.97}$
0.96	0.836	0.832	0.836	0.832
	.835	.831	.838	.834
	.830	.826	----------	----------
0.92	.856	.834	.851	.829
0.78	.899	.832	.903	.836
	.900	.833	----------	----------

Since each ratio is uncertain by about 0.004, the differences are not significant, and it may be concluded that the formula for thin samples applies to the solid-opal-glass standards within the experimental uncertainty. For much smaller effective areas, however, the amount of light lost through the edges might be appreciable; each particular condition of illuminating and viewing requires separate study.

[12] See footnote 4, p. 282.
[13] See footnote 1, p. 281

A similar test of the flashed-opal-glass standards showed formula 1 to be inapplicable by amounts exceeding 0.01 over the same range in reflectance, R', of backing. Such a result might have been expected because of the greater loss of light through the clear-glass edges between the flashed-opal back layer and the fine-ground front surface. A satisfactory treatment of these standards was obtained by the assumption that the two scattering layers separated by 1.5 mm would behave essentially like a single scattering layer located 0.5 mm away from the white backing. This latter case is handled by a previously derived approximate formula [14] extended so as to take account of absorption of light by the sample.

4. PERMANENCE

Since these standards have been made up only for a few months, no very conclusive evidence as to the constancy of their opacity is at hand. In 3 months none of the standards has shown any unexplained variations. While glass undergoes some alteration in surface character with time, there seems to be little basis for expecting a significant change in opacity of these standards. Periodic checks are planned as a test of this presumption.

IV. APPLICATION OF THE STANDARDS

Because of several advantages possessed by the solid-opal-glass standards, it is planned for the present to use them to the exclusion of the flashed-opal type. They are more suitable because (1) they are more uniform, (2) their opacity depends less on soiling, (3) the formula for thin samples may be used, (4) their opacities are close to those of the writing and printing papers chiefly tested, and (5) they introduce less chromaticity difference between the two halves of the photometric field.

The general plan of using the opal-glass standards is to issue one of them to the owner of an opacimeter together with values of reflectance for black backing, R_0, and of ideal contrast ratio, C. The recipient measures the standard on his opacimeter and obtains $C_{R'}$. This determines R' for the opacimeter under test according to the relation:

$$R' = \frac{C(1-C_{R'})}{C_{R'}(1-C)+R_0(C-C_{R'})} \tag{4}$$

which follows from formula 1.

If this value of reflectance of the surface or cavity in contact with the back of the sample conforms to the desired definition of opacity, the instrument is reading correctly. This value is 0.97 if true contrast ratio is being used; it is about 0.89, as will appear later, for the TAPPI definition of opacity. If the desired value of R' is not obtained either the operator may adjust the reflectance by suitable means until it reads correctly or he may compute opacity by formula 1 as discussed presently.

[14] See equation 5 in the paper referred to in footnote 3, p. 282.

1. DEPENDENCE ON POSITION OF THE SAMPLE

As just outlined, the use of the standards of opacity may be regarded as an indirect way of determining the reflectance of the surface or cavity in contact with the back surface of the standard. If the sample to be measured is placed so that its back surface occupies the plane previously occupied by the back surface of the standard, the method of calibration described gives the correct value of opacity. In some instruments, however, it is inconvenient to insert samples of varying thickness so that the back surfaces always lie in the same plane. This is the case with the present Bureau of Standards type of instrument; it is a minor defect of design. For these instruments account must be taken of the fact that the standards fill the slot which is only partially filled by the sample holder and thin sample; the result is that the back plane of the sample is 0.5 to 0.7 mm further from the white backing than the back plane of the standard.

In this case the reflectance of the cavity commencing approximately at the central plane of the standard instead of the back plane must be deduced from the opacity measurement of the standard. This is done by application of the approximate formula previously derived for the dependence of $C_{R'}$ on separation from the white backing [15] extended so as to take account of light absorption by the sample. It is found, and checked by experiment, that for this purpose the standard has to be assigned a value lower than the ideal contrast ratio by about 0.02. The remainder of the calibration, whether by adjustment of the instrument or by use of formula 1 is carried out as before. The calibration, however, is somewhat less certain because the position of the sample is imperfectly controlled.

2. DEPENDENCE ON LIGHT-ABSORPTION BY THE SAMPLE

In case it is not possible to adjust the value of R' (by substitution of a new white backing or by adjustment of the separation from the sample), or if it is preferred for other reasons to use formula 1 for computation of opacity, an approximate value of reflectance, R_0, is needed. This value may be estimated with sufficient accuracy for many samples of small light absorption by taking account of the known dependence of R_0 on thickness.

In the previous paper [16] it was assumed that formulas derived for nonabsorbing samples would apply to white paper and a good check was obtained for the samples tested which had $C_{.97}$ less than 0.75. By this assumption the sample in a thick layer would have unit reflectance, and since many kinds of papers have reflectivities of about 0.80, the assumption leads to appreciable error for samples of high opacity though the error is small for samples of lower opacity. A more accurate representation of actual samples regardless of opacity is obtained by taking $R_\infty = 0.80$. Table 3 shows corrections to be subtracted from instrument readings, $C_{R'}$, in order to obtain true contrast ratio, $C_{.97}$, for samples having reflectivities (R_∞) equal to 0.80.

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[15] See footnote 14, p. 286.
[16] See footnote 3, p. 282.

TABLE 3.—*Corrections to be subtracted from instrument readings, C_R', to give true contrast ratio, $C_{.97}$, for thin samples of a material having a reflectivity (R_∞) equal to 0.80*

	$(C_{R'}-C_{.97})$											
C_R'	$R'=0.76$	$R'=0.78$	$R'=0.80$	$R'=0.82$	$R'=0.84$	$R'=0.86$	$R'=0.88$	$R'=0.90$	$R'=0.92$	$R'=0.94$	$R'=0.96$	C_R'
0.00	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.00
.05	.010	.009	.008	.007	.006	.005	.004	.004	.003	.002	.001	.05
.10	.020	.019	.017	.015	.013	.011	.009	.007	.005	.003	.001	.10
.15	.030	.028	.025	.022	.019	.016	.013	.010	.008	.005	.002	.15
.20	.040	.037	.035	.029	.025	.021	.018	.014	.010	.006	.002	.20
.25	.050	.046	.041	.036	.031	.026	.022	.017	.012	.007	.002	.25
.30	.059	.054	.048	.043	.037	.032	.026	.020	.015	.009	.003	.30
.35	.068	.062	.056	.049	.043	.036	.030	.023	.017	.010	.004	.35
.40	.076	.069	.062	.055	.048	.041	.034	.026	.019	.012	.004	.40
.45	.083	.076	.068	.060	.053	.045	.037	.029	.021	.013	.004	.45
.50	.090	.082	.074	.065	.057	.049	.040	.032	.023	.014	.005	.50
.55	.096	.087	.078	.070	.061	.052	.043	.034	.024	.015	.005	.55
.60	.100	.091	.082	.073	.064	.055	.045	.035	.025	.016	.005	.60
.65	.103	.094	.085	.076	.066	.056	.047	.037	.026	.016	.005	.65
.70	.105	.096	.086	.076	.067	.057	.047	.037	.027	.016	.005	.70
.75	.103	.094	.085	.075	.066	.056	.046	.036	.026	.016	.005	.75
.80	.099	.090	.081	.072	.062	.053	.044	.034	.024	.015	.005	.80
.85	.090	.081	.073	.064	.056	.047	.039	.030	.022	.013	.004	.85
.90	.074	.067	.059	.052	.045	.038	.031	.024	.017	.010	.004	.90
.95	.047	.041	.037	.032	.028	.023	.019	.014	.010	.006	.002	.95
1.00	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	1.00

The values in table 3 were obtained by application of formulas 1 and 2. First, for various values of sx the corresponding values of R_0 and R_1 were computed from formula 2. Second, these values of R_0 were plotted against the ratio, R_0/R_1, which is ideal contrast ratio, C, and a smooth curve drawn through the points (see fig. 1, lower curve). Third, for enough values of C to determine the relation, $C_{R'}$ was computed by formula 1, the value of R_0 corresponding to each value of C being read from the curve (see fig 1); this was done for R' equal to 0.97, and for R' equal to 0.96, 0.94, 0.92, . . . 0.76. Fourth, the differences $C_{R'}-C_{.97}$ were computed, and the corrections given in table 3 obtained by graphical interpolation.

These corrections apply strictly to thin, homogeneous samples of material having a reflectivity (R_∞) of 0.80. In order to determine how accurately these corrections apply to actual samples, 13 papers were selected and R_0 and $C_{.96}$ measured for them. From these results values of ideal contrast ratio, C, were computed by formula 1. These values are plotted in fig 1 (circles). Figure 1 also shows the straight line, $R_0=C$, which refers to nonabsorbing samples ($R_\infty=1$). It is seen that the points representing actual paper samples fall about as much on one side of the curve for $R_\infty=0.80$ as on the other. For samples on or near the curve, the corrections of table 3 apply exactly; for those which fall far from it the corrections apply less exactly.

Table 4 shows values of R_0 and $C_{.96}$, obtained by measurement, and computed values of ideal contrast ratio, C, true contrast ratio, $C_{.97}$, and TAPPI opacity computed as $C_{.89}$. The differences, $C_{.89}-C_{.97}$, are also compared with the corrections read by interpolation from table 3. The final column gives the difference between $C_{.89}-C_{.97}$ and the corresponding correction read from table 3; it is seen that, as expected, the corrections are appreciably in error both for papers of very light color (100 percent rag bond) and for dark papers (newsprint), but they apply well to papers of intermediate lightness.

It may also be noted that the corrections of table 3 apply well to the solid-opal-glass standards (see point indicated by square in fig. 1).

V. OPACITY ACCORDING TO THE TAPPI DEFINITION

The definition of opacity for paper adopted by the Technical Association of the Pulp and Paper Industry [17] was intended to be

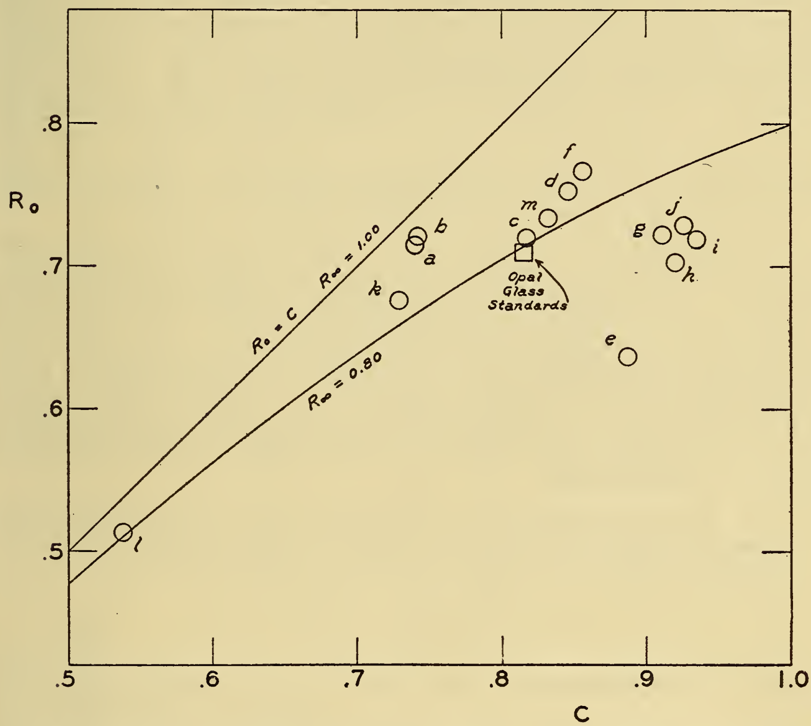

FIGURE 1.—*Relation between ideal contrast ratio, C and reflectance with black backing, R_0.*

The straight line, $R_0=C$, refers to nonabsorbing samples ($R_\infty=1.00$); the curve refers to samples made of various thicknesses of a material whose reflectivity (R_∞) is 0.80. The circles refer to paper samples identified in table 4.

equivalent to true contrast ratio, $C_{.97}$. However, the importance of the separation between sample and white backing was not well understood. As a result the method gives $C_{R'}$, where R' is somewhat lower than 0.97 because of interposition of a cover glass and is somewhat undefined because the reflectance of magnesium carbonate used as the white backing is not always the same and because the amount of separation is not stated. Much of the undesirable effect of this uncertainty in practice has been avoided by having many of the opacimeters compared with the instrument at the National Bureau of Standards.

[17] See footnote 2, p. 282.

Opacity by the TAPPI method, therefore, is determined by the adjustment of this particular instrument rather than by definition. Although this adjustment may not have been absolutely constant over a period of years, still there is some interest in determining the value of R' which characterizes the Bureau of Standards opacimeter because that value is probably the most reliable determinant of TAPPI opacity that can be obtained.

Accordingly two of the standards, A4 and B4, and three paper samples, j, k, l, of known reflectance, R_0, and ideal contrast ratio, C, were measured on the Bureau of Standards instrument. It was found by the method described in the preceding section that the reflectance, R', of the cavity commencing at the back of the standards is 0.92, while that of the cavity, deeper by about 0.6 mm, commencing at the back of the thinner paper samples is about 0.89. The corrections for $R'=0.89$ obtained by interpolation from table 3 indicate the difference between TAPPI opacity and true contrast ratio for samples made of material having a reflectance of 0.80 in a thick layer; the difference rises as high as 0.04 for some samples. Examples of this difference for actual samples are given in table 4 as $C_{.89}-C_{.97}$.

If a standard is to be used to check an opacimeter according to the TAPPI definition, an abridgement of the method of checking described in the previous section is possible. Instead of giving values of R_0 and C for the standard it suffices to give $C_{.92}$. The instrument is adjusted so as to give this value of opacity for the standard; then the sample holder is adjusted so as to place the paper samples 0.6 mm further from the white backing than the back of the opal-glass standard inserted without the holder. The instrument is then adjusted to give $C_{.89}$ for paper samples inserted in the holder provided the photometer is in adjustment.

Table 4.—*Ideal contrast ratio, C, true contrast ratio, $C_{.97}$, and approximate* TAPPI *opacity, $C_{.89}$, for representative paper samples showing applicability of the corrections given in table 3*

Sample	Type of paper	R_0	$C_{.96}$	C	$C_{.97}$	$C_{.89}$	$C_{.89}-C_{.97}$	Corrections read from table 3 for $R'=.89$	Error in the correction
a	100 percent rag bond	0.715	0.765	0.740	0.759	0.803	0.044	0.039	+0.005
b	do	.721	.768	.742	.761	.806	.045	.038	+.007
c	Book, no filler	.720	.837	.817	.832	.866	.034	.033	+.001
d	Book, clay filler	.753	.865	.846	.861	.892	.031	.028	+.003
e	Newsprint	.637	.897	.887	.895	.913	.018	.025	−.007
f	Book, clay filler	.767	.875	.856	.870	.901	.031	.028	+.003
g	do	.722	.922	.911	.919	.936	.017	.021	−.004
h	do	.703	.929	.920	.927	.942	.015	.018	−.003
i	do	.719	.943	.935	.941	.954	.013	.016	−.003
j	do	.729	.935	.926	.933	.948	.015	.017	−.002
k	Sulphite bond	.676	.752	.729	.747	.788	.041	.039	+.002
l	Manifold	.513	.558	.538	.553	.593	.040	.040	±.000
m	Mimeograph	.734	.851	.832	.847	.879	.032	.030	+.002

An abridged method of obtaining a calibration of the instrument for paper samples represented closely by the curve of figure 1 is also possible, provided the difference, $\Delta C_{.92}$, between the true value of

$C_{.92}$ for the standard and opacity given for it by the instrument is not too great (perhaps less than 0.03). This difference, $\Delta C_{.92}$, is a measure of how much the reflectance of the cavity departs from 0.92. To a first approximation the reflectance of the deeper cavity (deeper by 0.6 mm) commencing at the back of the paper sample will depart from 0.89 by the same amount, and the opacimeter will give a result correspondingly in error, say by $\Delta C_{.89}$. By application of formulas 1 and 2 as described in connection with table 3, the relation of $\Delta C_{.92}$ and $\Delta C_{.89}$ can be determined so that the corrections, $\Delta C_{.89}$, to be applied to readings on paper samples may be found directly from the correction for the standard, $\Delta C_{.92}$, without the need for computing R' explicitly. Table 5 gives the ratio, $\Delta C_{.89}/\Delta C_{.92}$, as a function of opacity, $C_{R'}$, given by the instrument assuming that the standard has $C_{.92}=0.85$, which is nearly true for the solid-opal-glass standards. These ratios may also be found from table 3 by taking the appropriate differences.[18]

TABLE 5.—*Relation between the corrections for paper samples, $\Delta C_{.89}$, and the correction for the standard, $\Delta C_{.92}$*

[These values are for papers having reflectivities (R_∞) of about 0.80]

Measured value of opacity $C_{R'}$	Ratio of error for a paper sample to error for the standard $\Delta C_{.89}/\Delta C_{.92}$	Measured value of opacity $C_{R'}$	Ratio of error for a paper sample to error for the standard $\Delta C_{.89}/\Delta C_{.92}$
0.00	0.0	0.50	1.0
.05	.1	.55	1.1
.10	.2	.60	1.2
.15	.3	.65	1.2
.20	.4	.70	1.2
.25	$.5_5$	.75	1.2
.30	.7	.80	1.1_5
.35	$.7_5$	.85	1.0
.40	$.8_5$	.90	.8
.45	.9	.95	.5
		1.00	0

The use of these ratios to find $C_{.89}$ for a paper sample is illustrated by the following example:

True value for $C_{.92}$ for the standard		0.854
Opacity of standard measured by instrument		.870
Instrument reads high by $\Delta C_{.92}$ equal to		.016
Opacity of a book paper by instrument, $C_{R'}$		.925
Ratio from table 5 for $C_{R'}=0.925$	0.7	
Correction, 0.016 x 0.7		.011
$C_{.89}$ for the book paper		.914

WASHINGTON, JULY 6, 1934.

[18] Detailed instructions for checking opacimeters of the type described in Bureau of Standards Circular C63 according to this method are given in NBS Letter Circular LC418, Standards for Checking Opacity Meters.